ERCOT Data Mining For Oscillations from Wind Generators

Sidharth Rajagopalan, ERCOT

Sarma Nuthalapati, ERCOT

Bill Blevins, ERCOT

John W. Ballance, EPG

Prashant C. Palayam, EPG

March 24 2015

NASPI Meeting – San Mateo, CA

Electric Power Group

ERCOT

DATA MINING FOR OSCILLATIONS - OUTLINE

- Discovery Across Texas (DAT) – DOE Funded Project
- Background & Purpose
- Goals
- Study Objective
- Methodology and Approach Used
- Data Mining Results
- Comparative Analysis with Wind Production
- Benefit & Success Story

Discovery Across Texas

Regional Demonstration Grant DOE-OE-0000194 Awarded to Center for Commercialization of Electric Technologies (CCET)

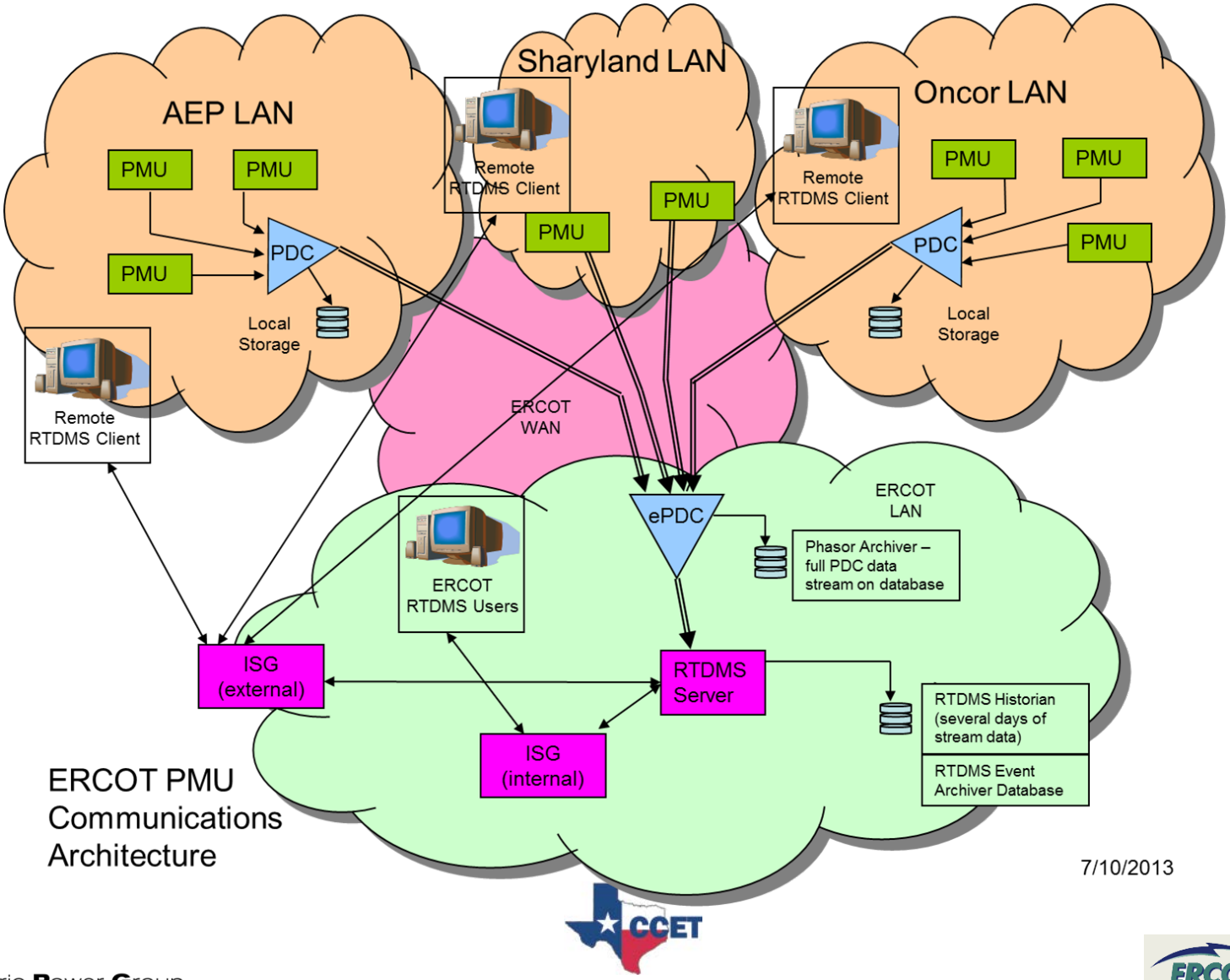
- Project Focus on Wind Resource Integration, Synchrophasor Technologies, Batteries and Energy Portal
- Synchrophasor Project Lead – Electric Power Group – Synchrophasor Applications, Technology Integration, Data Analysis and Project Coordination
- Synchrophasor Project TO/asset owner partners
  - American Electric Power - Texas – 18 locations*, 1 PDC
  - Oncor Electric Delivery - 15 locations*, 3 PDCs
  - Sharyland Utilities - 3 locations*, 1 PDC
  - Electric Reliability Council Of Texas (ERCOT) - RTDMS® visualization platform, *e*PDC, data archiving, PGDA event analysis
  - Texas Tech University – Wind Science and Engineering Center – wind and battery storage performance, 4+ PMUs, 1 *e*PDC, RTDMS®, Security Fabric Demo

*

	Total Planned Locations	Committed for Cost Share
AEP	18	4
Oncor	15	12
Sharyland	3	3
Texas Tech	5	-

Electric Power Group

ERCOT PHASOR NETWORK



Oscillations Data Mining - Background & Purpose

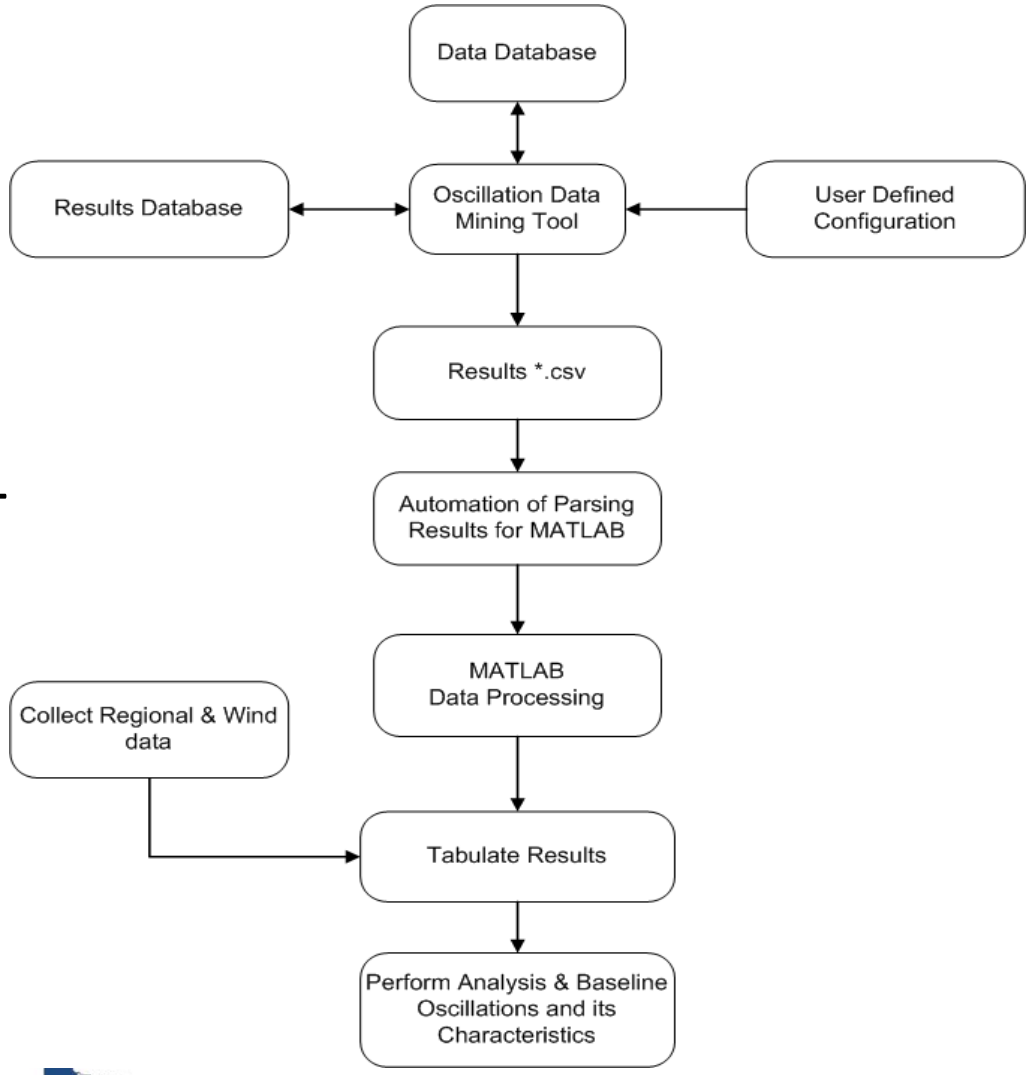
- Texas has the largest amount of wind generation on-line in the nation and has built a transmission upgrade to support increased wind production.
- Early Detection & Mitigation of Oscillations can prevent system vulnerability and customer complaints
- These Oscillations can grow at high energy with increasing level of Wind Generation
- Baselining grid oscillations and monitoring for them in real-time is becoming important to reliable operation of grid
- Purpose – Perform phasor data mining analytics to investigate oscillations in ERCOT Interconnection and study its impact with increasing levels of Wind Generation

Goals

- Determine Occurrence of Oscillations – Location, Type and Severity, Timing, Source
- Discover Unknown or New Oscillations for Real Time Monitoring
- Determine Sources of Unknown Oscillations
- Determine the type of Identified Oscillations – Wind Related or driven by Control System
- Baseline Oscillations Characteristics – Mode Damping & Energy for Real-time Monitoring

Methodology

- Phasor Data (2012-2014)
- Regional Wind – EMS Data
- Phasor Data Mining Tool
- Establish Mining Criteria – Using Mode Meter in PGDA
- Calculate Mode Statistics – Using MATLAB
- Baseline Oscillation Characteristics & Type



Electric Power Group

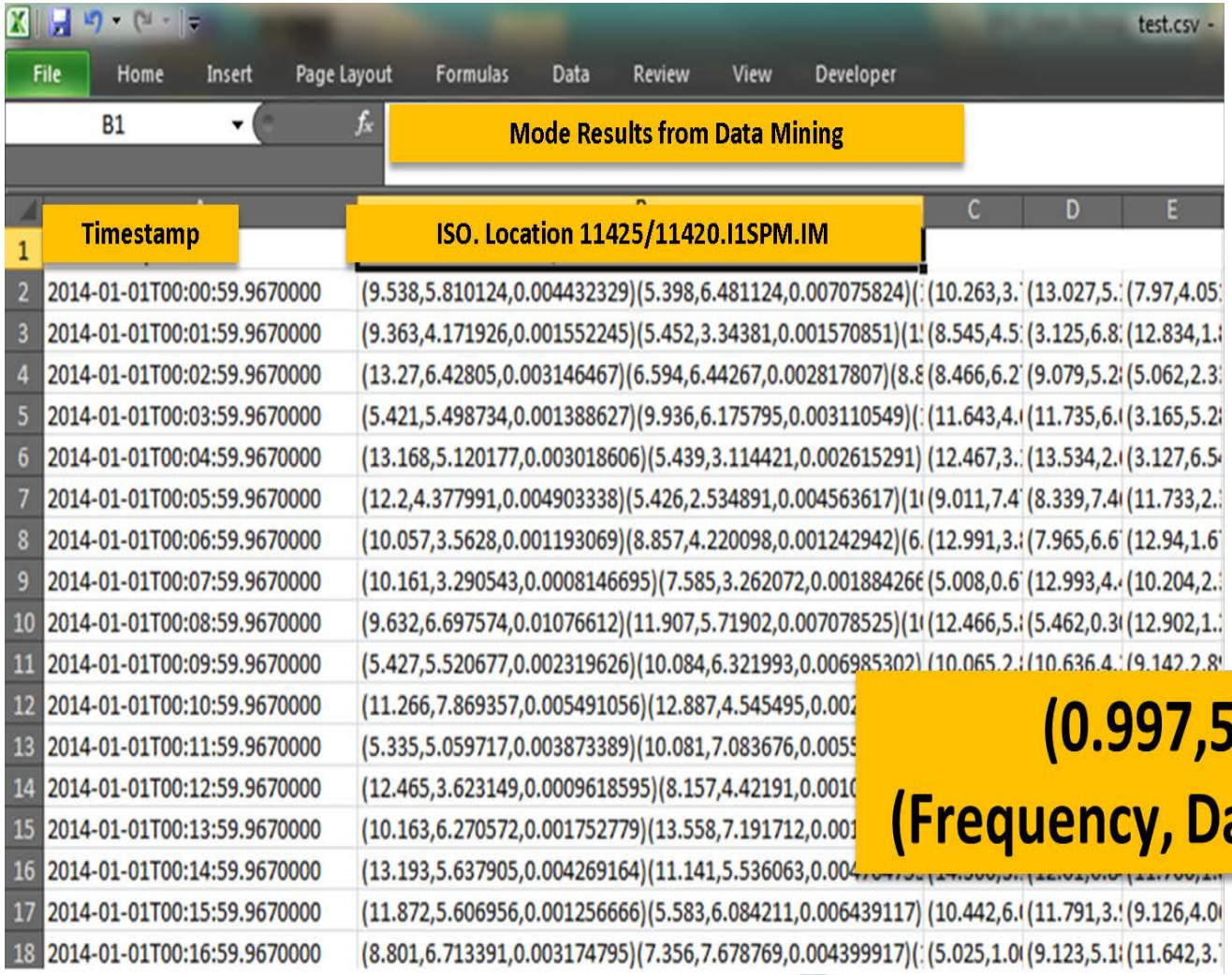
Mining Criteria – Mode Meter Algorithm

- Algorithm Used – Yule Walker Spectral
- Extracts 1-Minute of PMU data and scans for oscillations
- Included 7 PMU locations at nearby Wind Farms
- PMU data is cleaned using PMU Status Flags
- Captures Frequency of Oscillations till 15 Hz
- Filters Used
  - Damping < 8%
  - Minimum Energy = 0
- Reports Results every Minute for each PMU Signal (3-Years)
  - (Frequency, Damping, Energy)

Results, Issues & Further Analysis

- Oscillations are always present in the power system - mining 3-years data identified millions of oscillations
- Observation - Most oscillations are not significant or worthy of operator attention
- Issue - Identifying oscillations of significance for operations from the millions of oscillations identified
- EPG Approach - Use data mining filters designed for oscillations to filter based on Energy, Damping, Frequency & Occurrence
- Results - Identified 10 previously unknown oscillations that are operationally significant; Correlated occurrence of oscillations with wind data to identify root cause

Oscillation Data Mining Results Extract



	Timestamp	ISO. Location 11425/11420.I1SPM.IM	C	D	E
2	2014-01-01T00:00:59.9670000	(9.538,5.810124,0.004432329)(5.398,6.481124,0.007075824)(	(10.263,3.	(13.027,5.	(7.97,4.05
3	2014-01-01T00:01:59.9670000	(9.363,4.171926,0.001552245)(5.452,3.34381,0.001570851)(1	(8.545,4.5	(3.125,6.8	(12.834,1.
4	2014-01-01T00:02:59.9670000	(13.27,6.42805,0.003146467)(6.594,6.44267,0.002817807)(8.8	(8.466,6.2	(9.079,5.2	(5.062,2.3
5	2014-01-01T00:03:59.9670000	(5.421,5.498734,0.001388627)(9.936,6.175795,0.003110549)(	(11.643,4.	(11.735,6.	(3.165,5.2
6	2014-01-01T00:04:59.9670000	(13.168,5.120177,0.003018606)(5.439,3.114421,0.002615291)	(12.467,3.	(13.534,2.	(3.127,6.5
7	2014-01-01T00:05:59.9670000	(12.2,4.377991,0.004903338)(5.426,2.534891,0.004563617)(1	(9.011,7.4	(8.339,7.4	(11.733,2.
8	2014-01-01T00:06:59.9670000	(10.057,3.5628,0.001193069)(8.857,4.220098,0.001242942)(6.	(12.991,3.	(7.965,6.6	(12.94,1.6
9	2014-01-01T00:07:59.9670000	(10.161,3.290543,0.0008146695)(7.585,3.262072,0.001884266	(5.008,0.6	(12.993,4.	(10.204,2.
10	2014-01-01T00:08:59.9670000	(9.632,6.697574,0.01076612)(11.907,5.71902,0.007078525)(1	(12.466,5.	(5.462,0.3	(12.902,1.
11	2014-01-01T00:09:59.9670000	(5.427,5.520677,0.002319626)(10.084,6.321993,0.006985302)	(10.065,2.	(10.636,4.	(9.142,2.8
12	2014-01-01T00:10:59.9670000	(11.266,7.869357,0.005491056)(12.887,4.545495,0.002			
13	2014-01-01T00:11:59.9670000	(5.335,5.059717,0.003873389)(10.081,7.083676,0.005			
14	2014-01-01T00:12:59.9670000	(12.465,3.623149,0.0009618595)(8.157,4.42191,0.001			
15	2014-01-01T00:13:59.9670000	(10.163,6.270572,0.001752779)(13.558,7.191712,0.001			
16	2014-01-01T00:14:59.9670000	(13.193,5.637905,0.004269164)(11.141,5.536063,0.004			
17	2014-01-01T00:15:59.9670000	(11.872,5.606956,0.001256666)(5.583,6.084211,0.006439117)	(10.442,6.	(11.791,3.	(9.126,4.0
18	2014-01-01T00:16:59.9670000	(8.801,6.713391,0.003174795)(7.356,7.678769,0.004399917)(	(5.025,1.0	(9.123,5.1	(11.642,3.

(0.997,5.81,3.5) –
(Frequency, Damping, Energy)

Electric Power Group

CCET

ERCOT

Identification of Significant Oscillations

- The Algorithm identified a myriad of oscillations and it was important to discriminate significant vs. trifling modes
- Planners and Operators need to focus on “Modes” that:
  - Occur most of time (High Occurrence)
  - Occur with high energy (High Magnitude)
- MATLAB Code was written to identify such critical “Modes” that: (Post Processing Filters)
  - Existence is “>=“ 20% of Highest Occurrence
  - Magnitude is “>=“ 20% of Highest Energy
- Unique Modes were identified from both sets and shortlisted Modes were used for further analysis

0.9Hz Statistics @ Location 1 (2012-2014)

	A	B	C	D	E	F	G	H	I
	Year_Month	PMU	Signal Name	Type	Frequency Range	Occurrence	Highest Energy	Mode	Timestamp
5	2013-02	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**45.8413**	11.7884	0.997	2013-02-25T21:28:59.9670000
1		Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**50.1994**	8.1133	0.999	2012-12-[illegible]T00:05:59.9670000
2		Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**39.233**	7.7537	0.999	2012-06-[illegible]T05:14:59.9670000
4	2014-06		ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**53.2759**	7.2395	0.998	2014-06-[illegible]T09:28:59.9670000
3	2013-01		ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**41.0998**	7.083	0.998	2013-01-[illegible]T22:01:59.9670000
6	2012-03	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**47.8126**	7.0[illegible]		
61	2013-05	Location1	ISO.Lo[illegible]SPM.IM	IM	0.9-1.0	**51.383**	6.9[illegible]		
64	2012-04	Location1	ISO.Lo[illegible]SPM.IM	IM	0.9-1.0	**42.7603**	5.6[illegible]		
19	2014-03	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**48.4109**	5.4[illegible]		
26	2013-10	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**43.3642**	4.7[illegible]		
10	2014-04	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**52.2464**	4.5[illegible]		
59	2014-05	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**41.2448**	4.2[illegible]		
70	2012-02	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**43.1459**	4.2485	0.997	2012-02-15T16:48:59.9670000
71	2014-01	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**37.5369**	4.0279	0.996	2014-01-27T10:53:59.9670000
20	2013-11	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**37.9806**	3.9562	0.999	2013-11-12T12:00:59.9670000
23	2014-02	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**39.1[illegible]**	3.8759	0.998	2014-02-28T17:34:59.9670000
12	2012-09	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**38.[illegible]**	3.5968	0.997	2012-09-08T01:49:59.9670000
55	2013-04	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**48.0477**	3.514	0.999	2013-04-18T05:46:59.9670000
69	2012-05	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**35.5253**	3.[illegible]	0.998	2012-05-31T04:02:59.9670000
97	2013-06	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**45.8399**	3.[illegible]	0.999	2013-06-18T00:20:59.9670000
00	2013-12	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**22.5049**	3.[illegible]	0.998	2013-12-21T19:38:59.9670000
62	2013-07	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**41.3679**	2.0264	0.997	2013-07-15T01:46:59.9670000
35	2012-11	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**44.1414**	1.9609		2012-11-23T13:28:59.9670000
00	2012-08	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**31.7742**	1.7488		2012-08-21T05:43:59.9670000
69	2012-07	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**30.9657**	1.1927	0.997	
76	2012-10	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**44.1637**	1.0211	0.998	
81	2013-08	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**39.1368**	0.91643	0.998	
27	2013-09	Location1	ISO.Location1 9205/9210.IASPM.IM	IM	0.9-1.0	**33.4557**	0.51827	0.968	2013-09-26T03:32:59.9670000

Time

PMU

Signal

Type

Range

Occurrence%

Highest Energy

Mode

Timestamp at Highest Energy

Feb 25 2013 @ 21:28:59 – Highest Energy at 0.9Hz

Electric Power Group

CCET

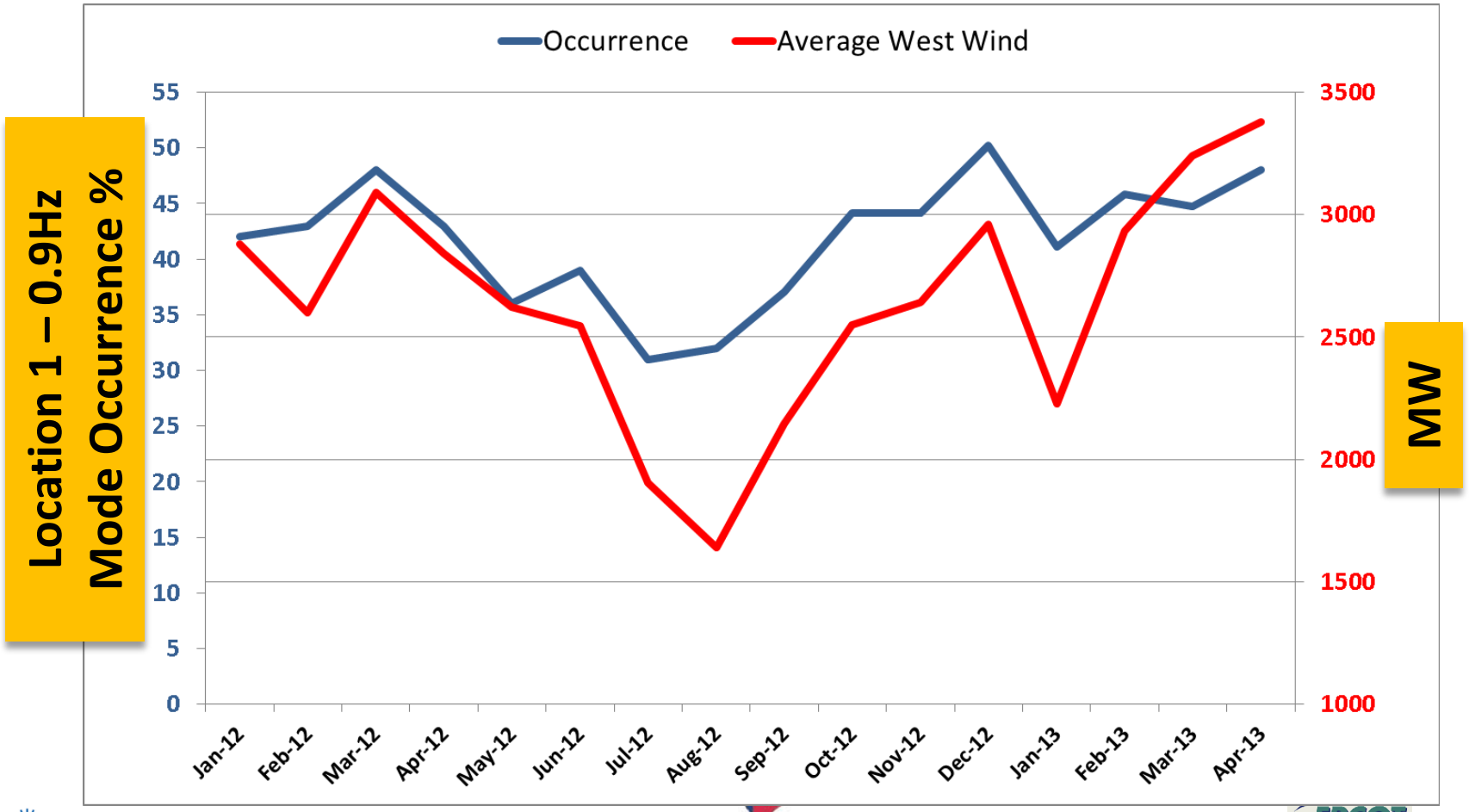
ERCOT

0.9Hz @ Location 1

- Highest Energy: Represents the highest energy of the mode during each month
  - Maximum Highest Energy in Feb 2013 and Energy was 12
  - Minimum Highest Energy in Sep 2013 and Energy was 0.5
- **Configuration for Additional Monitoring in Real-time**
  - Location 1 Current Magnitude
  - Minimum Frequency = 0.85Hz
  - Maximum Frequency = 1.2Hz
  - Minimum Energy = 2
  - Damping = 8%

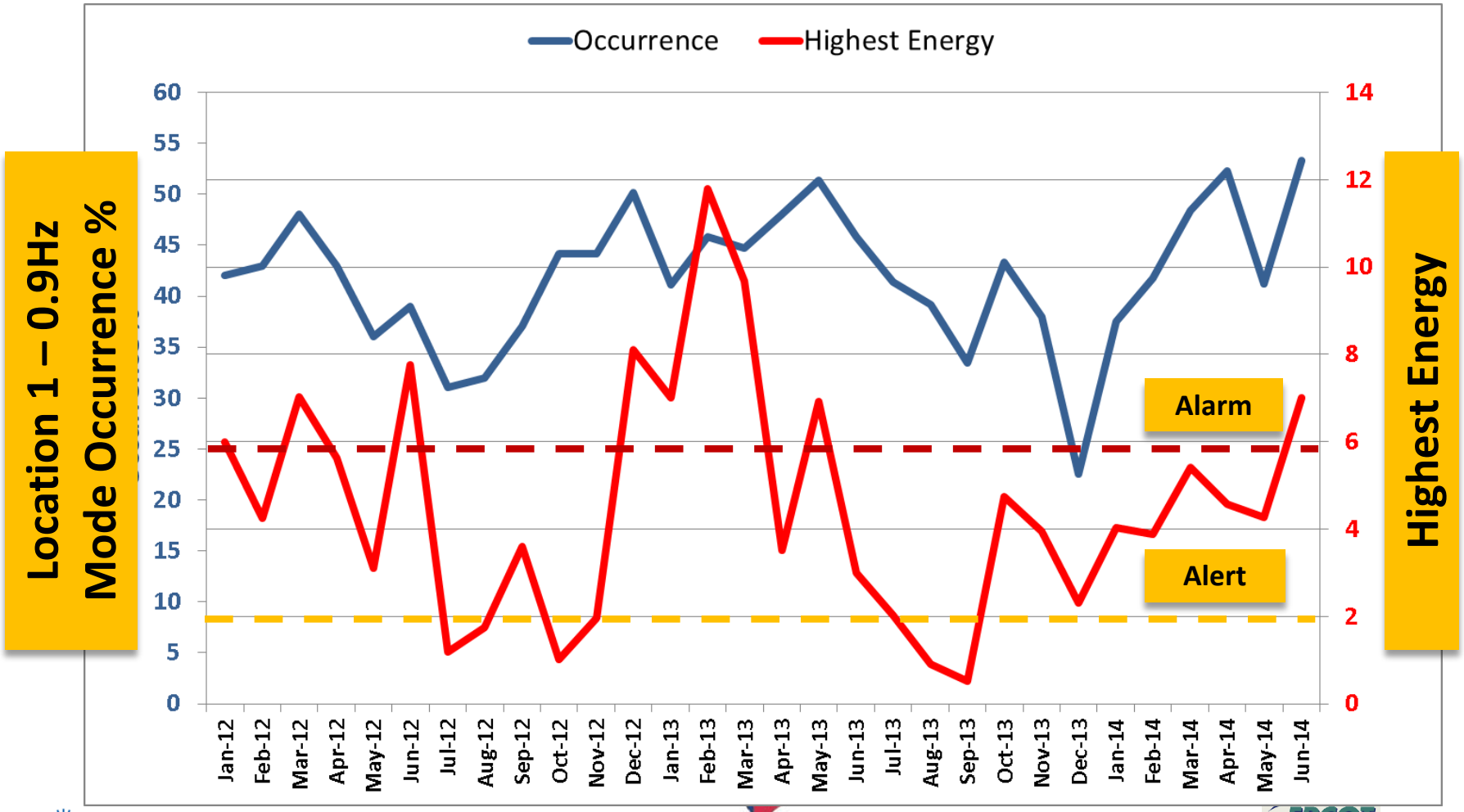
Comparison of Mode Occurrence & Wind Production

The Trend of Mode Occurrence & Average Wind have similar pattern and provides first indication that 0.9Hz is most likely related to wind production



Comparison of Mode Occurrence & Highest Energy

The peaks & valleys of Mode Occurrence & Highest Energy matched very well to provide second indication that 0.9Hz is most likely related to wind production near Location1



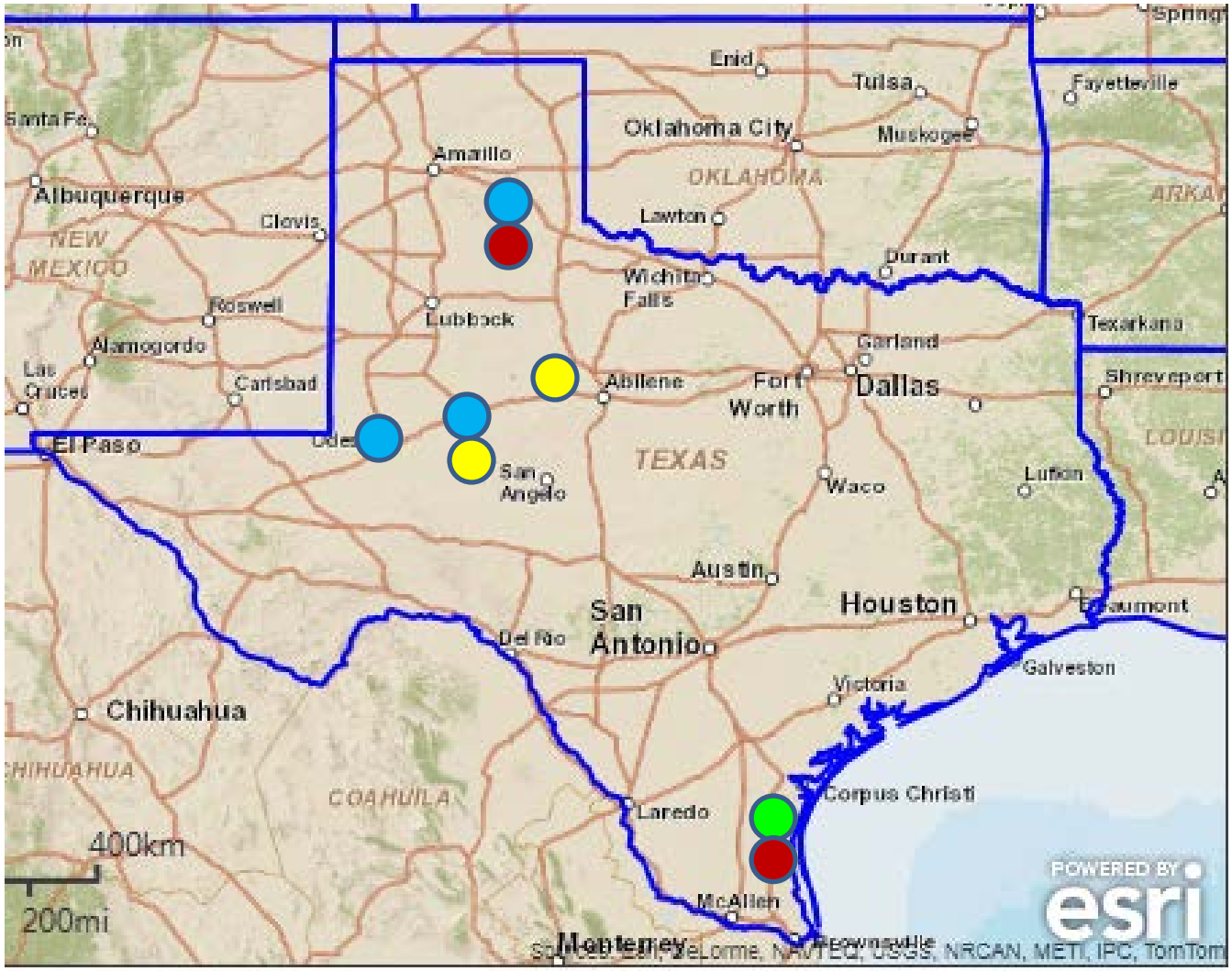
Electric Power Group

ERCOT

Identified 10 ERCOT Oscillatory Modes

#	Mode (Hz)	2012	2013	2014	Oscillation Type
1	**0.6**	Till March	Absent	Absent	Local
2	**0.9**	Present	Present	Present	Wind Production Related
3	**1.5**	Only in April	Absent	Absent	Control Systems
4	**1.7**	4 Months	Absent	Absent	Control Systems
5	**2.0**	Absent	April	Absent	Control Systems
6	**2.7**	Present	Present	Absent	Wind Production Related
7	**3.2**	4 Months	Absent	Only in Jan	Control Systems
8	**5.0**	Present	Present	Present	Control Systems
9	**5.4**	Present	Present	Present	Control Systems
10	**6.0**	Present	Present	Present	Control Systems

Identified 10 ERCOT Oscillatory Modes



- 0.9Hz, 2.7Hz – Wind production Related
- 5.0Hz – Control Systems
- 5.4Hz, 6.0Hz – Control Systems
- 3.2Hz, 1.5Hz, 2Hz – Control Settings

Electric Power Group

CCET

ERCOT

Identified 10 ERCOT Oscillatory Modes

#	Mode (Hz)	Nearest PMU	Related to Wind Production	Highest Energy Level
1	0.6	Location 2	No	Low Energy & Flat
2	0.9	Location 1	Yes	High Energy & Tracking Occurrence
3	1.5	Location 3	No	Low Energy
4	1.7	Location 4	No	High Energy
5	2.0	Location 3	No	Low Energy
6	2.7	Location 5	Yes	High Energy & Tracking Occurrence
7	3.2	Location 2	No	High Energy
8	5.0	Location 3	No	Low Energy & Remained Flat
9	5.4	Location 2, Location 5	No	Low Energy & Remained Flat
10	6.0	Location 2	No	Intermittent High Energy

BENEFIT & SUCCESS STORY

- Mined 3-Years of Phasor Data for Modes
- Identified 10 previously unknown and unmonitored Modes
- These Oscillations appear to be linked with:
  - Wind Production
  - Change in Control System Settings
  - Control Design
- **Prevention:** Obtained Insights on mode configuration in RTDMS® for additional monitoring and timely notification
- **Mitigation Action**: Validate with specific wind plant owners and implement changes to mitigate wind plant generated oscillatory modes
- **Additional Application of Data Mining Methodology**: (1) Mine events to establish alarm thresholds for real-time operations (not too many, not too few) (2) Identify grid zones vulnerable to specific events e.g., High Angle Difference & Low Voltage

Thank You.

Any questions ?